ESTIMATION OF MIXING RATIO PROFILES OVER MARITIME AREAS BY LINEAR REGRESSION METHODS

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THESIS

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by

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Estimation of Mixing Ratio Profiles Over Maritime Areas by Linear Regression Methods

by

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TABLE OF SYMBOLS AND ABBREVIATIONS

A	Intercept value for a regression equation
C_{jk}	kth regression coefficient for the jth predictand and kth predictor level
COEF-1	Regression coefficient set derived from OSV sounding data for all latitudes
COEF-2N	Regression coefficient set derived from OSV sounding data for latitudes $\phi \geq 50N$
COEF-2S	Regression coefficient set derived from OSV sounding data for latitudes $\phi < 50N$
e	Vapor pressure
e_s	Saturated vapor pressure
F	F-statistic for statistical confidence
λ	Pressure ratio exponent for power-profile
MLR	Acronym for multiple linear regression
N	Number of observations or size of data-sample
NESS	National Environmental Satellite Service
OSV	Ocean Station Vessels
OSV-1	OSV soundings comprising the dependent data-sample
OSV-2	OSV soundings comprising the independent data-sample
P	Pressure
ϕ	Latitude
RH	Relative humidity
R_M	Multiple regression correlation coefficient
R_{EFF}	Effective correlation coefficient
S_Y^2	Variance of Y

S.S.	Sum of squares
STD. ERR.	Standard error of estimate
U	Precipitable water vapor
W(J)	Mixing ratio at level J
$W_s(k)$	Saturated mixing ratio at predetermined level k
WC	Weinreb and Crosby
X	Independent variable
Y	Dependent variable
$(\hat{\ })$	Estimate of the quantity ( )
$(\bar{\ })$	Mean of the quantity ( )

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I. INTRODUCTION

Weinreb and Crosby (1973), (henceforth abbreviated WC), presented a useful technique for estimating atmospheric moisture profiles to assist in obtaining more accurate temperature retrievals from satellite soundings. Their estimation procedure was designed to derive the mixing ratios W at the lowest 40 levels of the 100-level atmosphere (McMillin, et al, 1973) defined in terms of linear j-increments of $P^{2/7}$ given by

$$P_j = .01(1.+(.26087836)(j-1)^{7/2} \qquad (1)$$

The saturated mixing ratio values $W_s(k)$ at 11 key levels are chosen as predictors from among the lowest 40 j-levels of eq. (1). In (1), as j = 01,...,100, P_j ranges over .01,...,1000 mb in the manner shown in Table 1. Table 1 also indicates the 11 fixed k-levels designated for computational use of the $W_s(k)$-values employed as predictors. The data set used by WC to establish the regression coefficients was deduced from 1100 island and coastal radiosondes with humidities reported to 200 mb. The WC radiosonde sample was distributed in an approximately random manner with respect to season and latitude.

The forty regression equations of WC were presented in the form

$$\hat{W}_j = \overline{W}_j + \sum_{k=1}^{11} C_{jk}(W_s(k)-\overline{W}_s(k)); \; j=1,...,40. \qquad (2)$$

Table 1. The 100 level atmosphere. Each j is an increment of $P^{2/7}$, j = 1,...100. Asterisked values are used for predictor levels in the regression analyses conducted.

Level j	Pressure P(j) (mb)	Level j	Pressure P(j) (mb)	Level j	Pressure P(j) (mb)
1	.0100	35	30.2057	68	271.2453
2	.0225	36	33.0936	69	284.8862
3	.0434	37	36.1735	70*	299.0103
4	.0756	38	39.4530	71	313.6275
5	.1219	39	42.9395	72	328.7482
6	.1857	40	46.6407	73	344.3825
7	.2703	41	50.5643	74	360.5408
8	.3794	42	54.7182	75	377.2336
9	.5168	43	59.1104	76	394.4712
10	.6866	44	63.7487	77*	412.2642
11	.8928	45	68.6414	78	430.6232
12	1.1398	46	73.7966	79	449.5589
13	1.4322	47	79.2225	80	469.0820
14	1.7746	48	84.9277	81	489.2033
15	2.1718	49	90.9204	82*	509.9337
16	2.6288	50	97.2092	83	531.2841
17	3.1507	51	103.8027	84	553.2655
18	3.7426	52	110.7097	85	575.8889
19	4.4100	53	117.9389	86	599.1655
20	5.1584	54	125.4991	87	623.1065
21	5.9933	55	133.3993	88	647.7231
22	6.9206	56	141.6484	89	673.0266
23	7.9461	57	150.2557	90*	699.0285
24	9.0758	58	159.2302	91	725.7401
25	10.3158	59	168.5812	92*	753.1729
26	11.6723	60	178.3181	93	781.3385
27	13.1517	61	188.4501	94*	810.2485
28	14.7804	62	198.9868	95	839.9147
29	16.5049	63*	209.9378	96*	870.3486
30	18.3920	64	221.3126	97	901.5623
31	20.4283	65	233.1209	98*	933.5674
32	22.6209	66*	245.3726	99	966.3760
33	24.9765	67	258.0774	100*	1000.0000
34	27.5024				

Equation (2) gives the format of the prediction equation where j is the level of the mixing ratio prediction, k is the predictor level and $\overline{W}_j$, $\overline{W}_s(k)$ the respective sample-means of W_j, $W_s(k)$ from the 1100 soundings. As seen in Table 1, the arrangement of the predictor levels (denoted by asterisks) takes primary advantage of the specification of the W_s-profile in the lower levels, yet allows for additional upper level influences.

The estimation method presented by WC demonstrated a strong multiple correlation between the predicted W_j values and the indicated saturated mixing ratio as predictands. However, in the collection of 1100 sample soundings, stratification of the regression results of WC by season was not considered. Additionally, in application to the computation of precipitable water vapor for radiometric (VTPR) calculations, island and coastal radiosondes were considered as being representative of open ocean areas.

In this thesis several multiple regression estimation formulas for water vapor porfiles are determined based upon the W_j and $W_s(k)$ data samples from only ten Ocean Station Vessels (OSV) distributed over the Atlantic and Pacific. However, the OSV data were based only on soundings from the month of January in the years 1967 through 1970, and so should possibly be considered representative of midwinter moisture predictions over the oceans. The regression formulas derived were based upon 1081 dependent data samples and then applied for independent test purposes upon a smaller

data sample drawn from the same set of OSV-soundings. Evaluation of the various estimation methods derived here was conducted in order to arrive at a "best" set of mixing-ratio specification equations. This prediction scheme was then compared with the WC prediction equations for the purpose of revealing the relative specification significance in the equations derived here. This evaluation was conducted using the smaller independent OSV data sample. Finally, a data-sample developed from 160 island and coastal soundings, collected from 1-28 March 1973 and similar to those used by WC (1973), was subjected to the "best" specification system developed here and compared with independent testing based on the use of the WC specification system.

A considerable amount of linear interpolation is required to adjust sounding data to the 100-level atmosphere, specifically to the levels 61 through 100. In this thesis and in the work done by WC simple linear interpolation on pressure raised to the 2/7$^{\text{ths}}$ power as listed in Table 1 is used. It is reasonable to assume that the regression coefficients determined by WC are not independent of one another over the 40-level system, and so could be reduced to a reasonably concise but smaller predictand set, say J=1,...,19. For purposes of this thesis, the best-fit multiple regression equation in the form of (2) was therefore applied only at the 19 levels listed in Table 2. It is to be noted that this set of 19 levels is a subset of the 40-level predictand set of WC and that it also includes the 11 levels used as

Table 2. 19-level atmosphere. The pressure levels P(J) are obtained by linear scaling of $P^{2/7}$ over the interval 188.45 mb to 1000 mb in 19 increments. Column 3 indicates the subset of predictor levels.

Level (J)	Predictand Pressure Level P(J) (mb)	$W_s(k)$ Predictor Levels (k)
1	188.45	
2	209.94	1
3	245.37	2
4	271.24	
5	299.01	3
6	328.75	
7	360.54	
8	412.26	4
9	469.08	
10	509.93	5
11	553.26	
12	599.16	
13	647.72	
14	699.03	6
15	753.17	7
16	810.25	8
17	870.35	9
18	933.56	10
19	1000.00	11

predictor-levels in their system. It was assumed that restricting Eq. (2) to 19-predictand levels would result in little, if any, loss of resolution of the estimated mixing ratio profiles over the lowest 40 WC predictand j-levels. Hence, comparison of the regression results deduced here will be with those results of WC at the 19-predictand levels adopted for use in this study.

Regression analysis was carried out on the IBM 360 computer using the BMD03R statistical program (Dixon, 1973).

II. DATA PROCESSING

A. OCEAN STATION VESSEL RADIOSONDES

The raw data used in this study consisted of a set of January radiosondes containing temperature and relative humidity data in accordance with standard radiosonde reporting procedures, i.e. available mandatory level plus any significant levels (Radiosonde Observations Handbook, 1969), from the 10 OSVs. Table 3 gives the approximate latitude and longitude for each of the OSVs in addition to the sample-size contributed by each to the total data set. Also listed in Table 3 is a similar breakdown of the sample size contributions to the total dependent and independent data samples (abbreviated as OSV-1, and OSV-2, respectively). The latter two data samples will be discussed later in this section.

Each sounding included in the OSV data samples was required to have temperature data up to at least 150 mb and relative humidity data to 450 mb. Both mandatory and significant levels were combined to produce temperature and relative humidity profiles at pressure levels arranged in order from 1000 mb to 150 mb.

B. REDUCTION OF RADIOSONDE OBSERVATIONS

Once a radiosonde was arranged in a pressure-decreasing order the Goff-Gratch formula in the form (List, 1963)

Table 3. Radiosonde-data sample sizes from Ocean Station Vessels, and their geographic locations.

OSV	POSITION LATITUDE	POSITION LONGITUDE	TOTAL OSV	NUMBER OF SOUNDINGS IN SAMPLES DEPENDENT DATA (OSV-1)	NUMBER OF SOUNDINGS IN SAMPLES INDEPENDENT DATA (OSV-2)
A	62.5N	33.0W	194	97	97
B	56.5N	50.5W	154	77	77
C	53.5N	35.5W	189	95	94
I	59.0N	19.0W	212	106	106
J	53.5N	19.5W	206	103	103
P	50.0N	145.0W	202	101	101
D	44.5N	41.0W	169	113	56
E	35.0N	48.5W	185	123	62
N	30.0N	140.0W	205	136	69
V	38.0N	165.0W	194	130	64
TOTALS			1910	1081	829

$$\log(e_s/P_0) = -7.90298((T_s/T)-1)+5.02808 \log(T_s/T)$$

$$-1.3816 \times 10^{-7}(10^{11.334(1-T/T_s)}-1)$$

$$+8.1328 \times 10^{-3}[10^{-3.49149((T_s/T)-1)}-1], \qquad (3)$$

where $T_s = 373.16°K$, $P_0 = 1013.246$ mb, and $T = T(P)$ is the temperature at pressure P, was used to determine saturated vapor pressures W_s. From the value of e_s, $W_s(P)$ was determined from

$$W_s(P) = \frac{.622\ e_s}{P - e_s} \qquad (4)$$

which in turn yielded the actual mixing ratio W(P) upon application of the relationship between RH (as a fraction) and W_s

$$W(P) = RH \times W_s(P) \qquad (5)$$

Following this procedure, simple linear interpolation of both T(P) and W(P) relative to the $[P(J)]^{2/7}$ values of Table 2 was performed, yielding a temperature profile T(J) up to 188.45 mb and a mixing ratio profile W(J) to 469.08 mb. Equations (3) and (4) were again needed to establish the 11-predictor values of $W_s(k)$; in this case $T = T(k)$, $P = P(k)$, $k=1,\ldots,11$, as shown in Table 2.

Since mixing ratio (or RH) profiles were usually unavailable in the radiosondes above 450 mb, the well known cubic power-law profile of Smith (1966) expressing W in the form

$$W = W_{ref}(P/P_{ref})^{\lambda}, \quad \lambda \doteq 3 \qquad (6)$$

was used. Here W_{ref} and P_{ref} signify the simultaneous conditions at the reference level, taken here as P_{ref} = 469.08 mb. Equation (6) was employed to compute "observational" values of W at all levels above P_{ref} to complete the 19 levels of Table 2.

Completion of the above procedures through (6) yielded, for each sounding, an array of 19 values of W and 11 values of W_s. These values were arranged in a final 30-variable format [$W(1), W(2), \ldots, W(19), W_s(1), W_s(2), \ldots, W_s(11)$]. This format was found to be most convenient accessing the least squares statistical program, BMD03R.

C. DIVISION OF DATA SAMPLES

The collection of 1910 OSV soundings was divided into two major data samples, OSV-1 consisting of 1081 total soundings, and OSV-2, comprised of the remaining 829. OSV-2 data were obtained by selecting a random mix of every second to every third sounding from the total set of soundings available from each ship, with the remainder going into the dependent sample OSV-1. Table 3 lists the contributions to each sample on a ship by ship basis. OSV-1 was used for determination of the dependent-test set of regression equations, for W(J) specified in terms of the predictor-variables $W_s(1), \ldots W_s(11)$. OSV-2 was used for independent or verification tests of regression results developed using OSV-1.

An additional subdivision of the OSV data was made to determine latitudinal effects, if any, on the moisture estimation regressions. This subdivision was suggested after

consideration of the distributions of the mean mixing ratios W(J) for each ship station in the OSV-1 data sample.

Table 4 lists the mean W-values by level for the entire dependent sample set, the subdivisions of the sample according to $\phi \geq 50N$, and $\phi < 50N$, as well as by individual ships. It seemed plausible to use 50N as the dividing point for the latitudinal zones as this arrangement provided reasonably large sample sizes to stratify the regression analyses in addition to maintaining the apparent stratifications demonstrated by the mean distributions. Although Ship Station P was located at 50N, its W-profile statistics seemed to be described more closely by the means of the northern set as its verification statistics suggest (Sec. IV.B.1).

Verification of the estimation equations derived by the latitudinal stratification of the dependent sample set was conducted on the stratifications (a) all ϕ, (b) $\phi \geq 50N$, (c) $\phi < 50N$ as well as for the individual ship-data samples reserved for the independent OSV-2 sample. The results of the tests on the individual ships are tabulated in Appendix B.

D. ISLAND AND COASTAL RADIOSONDE SAMPLE

Data collected under the auspices of the NATIONAL ENVIRONMENTAL SATELLITE SERVICE (NESS) during March, 1973, were used for additional testing of the estimation procedures. This data set provided a total of 160 typical radiosondes containing moisture data from the surface up to at least level J=9 of the pressure scale of Table 2 but with temperatures

Table 4 (a). Mean W-profiles for OSV-1 data, gm/100kg.

		Stratification		Individual Ships									
Level	All ϕ	$\phi \geq 50$	$\phi<50$	A	B	C	I	J	P	D	E	N	V
1	2.30	1.73	2.95	1.58	1.64	1.47	1.60	1.83	1.56	2.06	2.59	3.42	2.77
2	3.20	2.38	4.14	2.17	2.31	2.06	2.18	2.52	2.18	2.89	3.63	4.80	3.89
3	5.01	3.73	6.49	3.39	3.61	3.23	3.39	3.94	3.42	4.53	5.69	7.52	6.11
4	6.86	5.11	8.87	4.66	4.96	4.43	4.65	5.41	4.69	6.21	7.80	10.26	8.36
5	8.96	6.69	11.57	6.09	6.49	5.80	6.08	7.08	6.14	8.12	10.21	13.36	10.93
6	12.36	9.23	15.97	8.56	8.75	7.83	8.55	9.95	8.29	10.96	13.77	19.93	14.43
7	16.84	12.17	22.24	11.24	11.56	10.37	11.21	13.06	11.05	14.73	18.37	28.36	19.02
8	27.90	18.89	38.29	16.72	18.15	16.43	16.92	20.10	17.74	24.77	30.00	48.45	32.13
9	44.97	31.65	60.33	26.70	29.99	27.93	28.04	34.86	28.82	42.35	48.93	78.61	56.75
10	59.31	42.63	78.55	34.76	41.48	39.88	37.50	47.21	38.98	57.17	63.34	101.48	74.53
11	68.70	50.41	89.81	40.94	49.33	48.14	45.50	57.38	45.57	66.96	71.92	115.17	85.24
12	98.61	73.45	127.66	58.41	73.65	72.92	68.11	86.09	64.94	97.92	108.14	153.79	119.22
13	126.16	96.96	159.87	80.50	88.77	94.83	94.67	114.26	80.55	127.20	141.59	187.67	154.81
14	158.88	123.20	200.06	104.00	114.80	124.48	122.91	144.15	104.35	167.46	195.11	225.91	202.43
15	207.93	160.75	262.37	146.68	148.43	164.30	170.87	194.65	134.18	223.07	266.34	279.23	270.11
16	284.86	211.92	369.00	193.90	189.31	224.88	223.17	252.17	177.35	304.96	375.46	389.88	341.46
17	383.83	279.01	504.73	251.77	237.51	308.39	287.17	334.73	230.98	400.04	535.27	588.50	442.80
18	485.01	357.19	632.46	321.77	276.80	379.09	382.57	446.38	296.22	478.93	669.00	777.05	562.34
19	597.93	448.75	769.99	405.54	322.08	452.52	504.65	580.76	377.50	583.64	793.31	954.67	701.72

(b). Standard deviations of the W-profiles corresponding to part a.

1	1.61	1.09	1.84	0.96	0.89	0.90	1.03	1.29	0.98	1.35	2.15	1.89	1.62
2	2.25	1.51	2.58	1.32	1.25	1.26	1.38	1.77	1.38	1.90	3.02	2.65	2.28
3	3.54	2.37	4.05	2.07	1.96	1.98	2.16	2.78	2.16	2.98	4.74	4.16	3.57
4	4.82	3.25	5.51	2.84	2.69	2.72	2.97	3.81	2.97	4.09	6.50	5.70	4.89
5	6.29	4.25	7.18	3.72	3.53	3.56	3.88	4.99	3.88	5.35	8.50	7.47	6.40
6	9.11	5.88	10.71	5.22	4.76	4.80	5.46	7.01	5.24	7.22	11.41	12.80	9.30
7	13.30	7.84	15.99	6.86	6.46	6.46	7.16	9.20	7.22	9.78	14.86	20.09	13.49
8	24.47	12.72	30.04	10.49	11.39	10.66	10.99	14.04	12.56	17.14	24.81	37.30	26.78
9	39.33	22.35	48.14	18.48	20.53	19.63	20.06	24.92	21.41	30.11	41.49	60.13	51.74
10	50.86	30.41	61.78	24.26	28.93	28.06	26.76	33.20	30.17	42.02	51.77	75.74	64.32
11	57.23	35.71	68.96	28.02	34.31	32.59	30.69	38.59	35.86	51.13	55.55	81.88	73.22
12	81.01	51.89	97.26	41.79	52.01	50.16	43.83	55.88	52.76	80.89	83.50	105.01	98.13
13	100.06	65.97	120.16	51.64	63.19	62.77	53.64	63.66	64.68	104.26	108.64	122.98	124.43
14	121.43	84.73	142.58	65.27	82.11	85.13	68.76	80.12	82.78	129.85	137.22	135.92	152.27
15	142.09	96.94	164.72	76.52	100.68	102.46	77.01	92.10	96.91	144.53	159.81	165.96	180.07
16	164.07	109.65	175.82	92.29	113.08	111.24	91.27	107.12	102.76	142.45	167.68	178.93	184.16
17	189.57	119.08	183.74	97.32	114.94	118.70	98.66	109.08	104.58	138.88	161.15	160.11	182.08
18	222.30	129.26	215.94	102.18	108.93	137.97	108.62	113.87	109.15	160.06	189.40	147.98	198.10
19	262.33	150.22	258.86	114.74	106.77	132.73	129.51	131.79	100.62	190.47	226.50	185.71	239.42

up to at least level 1. The format of the soundings was much the same as that of the OSV data except that the moisture element was given in terms of the dew point T_d rather than RH. This difference required the use of Eq. (3) with e_s and T replaced by e and T_d, respectively, followed by application of Eq. (4) to obtain the W-values. All other procedures in this section apply to the NESS data to obtain soundings in the form $[W(1),W(2),...,W(J),W_s(1),W_s(2),...W_s(11)]$, where J is at least as high as level 9. Recall that $W_s(1),W_s(2),...,W_s(11)$ depend simply upon having the temperature profile complete in the form of Table 2 to level $P(2) = 209.94$ mb, and that for purposes of computing $W_s(k)$, the indexing k=1,...,11 denotes the indicated subset of the J-values shown in column 3 of Table 2.

E. VERTICAL WEIGHTING

With the mixing ratios estimated at most of the 19 levels of Table 2, it was possible to compute precipitable water vapor for each sounding as a measure of the vertically integrated mixing ratios. The precipitable water vapor, calculated by means of the finite-difference integration, Eq. (7).

$$U = \frac{1000}{980} \frac{\sum_{J=18}^{1\leq J\leq 9} (W_{J+1}+W_J)(P_{J+1}-P_J)}{2} \tag{7}$$

provided a basis for testing "estimated" precipitable water vapor against the corresponding "observed" U-values deduced from the W-profiles summed over the same atmospheric levels from level J downward. In the case of OSV soundings the

summation of Eq. (7) extended up to $J=1$; however in the case of the NESS data, the top level of humidity reports extended up to a level J in the range $1 \leq J \leq 9$.

III. STATISTICAL CONCEPTS AND PROCEDURES

A. MULTIPLE LINEAR REGRESSION

This thesis makes use of multiple linear regression (MLR) techniques to develop an effective specification scheme to estimate mixing ratio values at the 19 previously designated pressure levels, using as predictors, the saturated mixing ratios obtained at the 11 key levels specified by WC. In the discussion to follow, the phraseology "dependent variable" refers to observed mixing ratios to be specified in terms of the independent variables when MLR techniques are to be applied. The independent variables are always the set of saturated mixing ratios computed at the 11 specified levels in the vertical soundings.

Assuming that the dependent variable Y depends on k independent variables $(X_1, X_2, \ldots, X_k)$, and that there is a sample of N observations of the k+1 variables $(Y, X_1, X_2, \ldots, X_k)$, MLR techniques can be applied to find the best-fit multiple regression coefficients C_j. Y can be estimated by the regression equation

$$\hat{Y} = A + \sum_{j=1}^{k} C_j X_j \tag{8}$$

where the superscripted symbol $\hat{Y}$ denotes "estimation of Y."

Also it follows, from the requirement that the regression plane pass through the sample mean, that

$$A = \overline{Y} - \sum_{j=1}^{k} C_j \overline{X}_j . \tag{9}$$

The quantities ($\bar{\ }$) signify the respective means based on the sample size N.

It should be noted that Eqs. 8 and 9 can be combined to produce the form

$$\hat{Y} - \bar{Y} = \sum_{j=1}^{k} C_j(X_j - \bar{X}_j) \tag{10}$$

where the C_j's are the best-fit regression coefficients determined by MLR techniques.

The regression coefficients of (10) are determined by solving the system of normal equations given in determinant form by

$$\left|C_1, C_2, \ldots, C_k\right| \cdot \begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & a_{2k} \\ \vdots & & & \vdots \\ a_{k1} & \cdots & \cdots & a_{kk} \end{vmatrix} = \begin{vmatrix} a_{1y} \\ a_{2y} \\ \vdots \\ a_{ky} \end{vmatrix}, \tag{11}$$

where a_{ij} and a_{iy} are given by

$$a_{ij} = \sum_{m=1}^{N}(X_{im} - \bar{X}_i)(X_{jm} - \bar{X}_j), \tag{12}$$

and

$$a_{iy} = \sum_{m=1}^{N}(X_{im} - \bar{X}_i)(Y_m - \bar{Y}), \tag{13}$$

respectively.

In Eqs. (12) and (13) it is understood that $(Y^{(m)}, X_1^{(m)}, \ldots, X_k^{(m)})$ constitute the mth sample of Y on X_i. For simplification the superscript in this sample designation has been

written as a subscript in (12) and (13). From Eq. (12), $a_{ij} = a_{ji}$, and therefore, the matrix of $\{a_{ij}\}$ in (11) is symmetric. Equation (11) represents a system of k equations in the k unknowns C_i which can be solved for a unique set of regression coefficients, provided the k-by-k determinant of the left hand side of (11) is non-singular. If the multiplication of the left hand terms of (11) is carried out, one can obtain k equations in the form

$$a_{k1}C_1 + a_{k2}C_2 + \ldots + a_{kk}C_k = a_{ky} \tag{14}$$

which can be solved (Crow, et al., 1955) by matrix inversion methods applied to $\{a_{ij}\}$.

B. SIGNIFICANCE TESTS

1. On Dependent Regression Equations

The coefficient of determination of an MLR technique is definable as the ratio of the sum of squares due to the regression to the total sum of squares. This parameter may be shown to be the square of the multiple correlation coefficient, R_M^2,

$$R_M^2 = \frac{\text{Sum Sq. Explained by Reg.}}{\text{Sum Sq. of Total Deviation}} = \frac{[\sum_{i=1}^{N}(\hat{Y}_i-\overline{Y})^2]}{[\sum_{i=1}^{N}(\hat{Y}_i-\overline{Y})^2]}, \tag{15}$$

and is used as a measure of the efficiency of the regression performed by the BMD03R program. The total sum of squares

$$\text{S.S. total} = \sum_{i=1}^{N}(Y_i-\overline{Y})^2 = \sum_{i=1}^{N}[(\hat{Y}_i-\overline{Y})+(Y_i-\hat{Y}_i)]^2 = (N-1)S_Y^2 \tag{16}$$

defines the variance S_Y^2. S.S. total may be expanded

$$\text{S.S. total} = \sum_{i=1}^{N}(Y_i-\overline{Y})^2 = \sum_{i=1}^{N}(\hat{Y}_i-\overline{Y})^2+\sum_{i=1}^{N}(Y_i-\hat{Y}_i)^2 \qquad (17)$$

$$(a) \quad + \quad (b)$$

which is a combination of the S.S. due to regression (a), and the residual S.S. (b).

If the regression were perfect, term (b) of (17) would vanish and R_M^2 would be 1; conversely, if Y were totally independent of X_i, R_M^2 would be 0. Combination of Eqs. (15) and (17) shows that the residual sum of squares after application of the regression (8) is

$$\text{Res. S.S.} = (1 - R_M^2) \sum_{i=1}^{N}(Y_i-\overline{Y})^2 \; .$$

A method of determining the significance of a prediction equation having k predictors is the F-statistic with k and N-k-1 degrees of freedom, defined by

$$F(k,N\text{-}k\text{-}1) \equiv \frac{\text{Mean Square Explained by the Prediction}}{\text{Mean Square Unexpl. after the Prediction}} , \qquad (18)$$

or

$$F(k,N\text{-}k\text{-}1) = \frac{R_M^2/k}{(1-R_M^2)/(N-k-1)} \; . \qquad (19)$$

Equation 19 is a direct application of the definition (18) of the F-statistic for the appropriate degrees of freedom. For the numerator of (19), k is the number of independent variables used in specifying the mean square explained of (18). In the denominator of (19) the degrees of

freedom (df) is equal to N-k-1, corresponding to the total sample size, reduced by the 11 known coefficients and the value of the sample mean. In the tests on the dependent sample k=11 throughout, although N varies from test-sample to sample.

Critical values of the F-statistic, designated F_c, can be found in standard texts on statistics for the appropriate degrees of freedom at specified levels of significance. If the F-statistic of (18) exceeds $F_{.01}(k, N-k-1)$, there is less than 1% probability that the sample came from a population in which there is no linear relationship between Y and X_i. Such a statistical outcome for the regression is described as corresponding to a 99% level of confidence.

A third related statistic which is listed as output by BMD03R is the standard error of estimate (after application of the regression) is defined by

$$(\text{STD. ERR.})^2 \equiv \frac{\text{S.S. Errors}}{(N-k-1)} = \frac{\Sigma(Y_i-\hat{Y}_i)^2}{(N-k-1)} \qquad (20)$$

Equation (20) shows that the standard error is simply the square root of the mean of the errors squared. The standard error is related to R_M^2 by

$$(\text{STD. ERR.})^2 = \frac{(N-1)S_Y^2(1-R_M^2)}{(N-k-1)} \qquad (21)$$

The three statistics defined in (15), (18), and (20) were considered as comparative measures of the MLR techniques of this work and were conveniently provided as a standard output from the BMD03R program. Values of R_M, STD. ERR., and F are presented in tabular form in Section IV, based upon MLR techniques applied to relevant subdivisions of both dependent and independent samples.

2. <u>On Independent Data for Level by Level Analysis</u>

Similar test procedures were applied to evaluate estimates of the regression methods from Sec. III.A.1 to the independent OSV-2 sample. Slight variations in the degrees of freedom were required in specifying the efficiency statistics defined by Eqs. (15), (18), and (20) to the independent samples. In the regression analyses applied to the dependent sample, 11 predictors and the mean were used in arriving at N-12 degrees of freedom in the denominator. However once the coefficients were applied to the OSV-2 sample, there was essentially only one way to form the estimations $\hat{Y}$, using the prescribed set of coefficients. Therefore, in this section the df corresponding to k was taken as 1. R_M^2 was also somewhat modified and was termed simply R_{EFF}^2, defined as the effective coefficient of determination. The R_{EFF}^2 values were defined by

$$R_{EFF}^2 \equiv 1 - \frac{\text{S.S. Errors}}{\text{S.S. Total}} \tag{22}$$

The F-statistic and the standard error of estimate were calculated in a manner similar to Eqs. (19) and (20) with k=1, but with N-k-1 replaced by N-1. The resulting expression for these statistics

$$F = \frac{R^2_{EFF}}{(1-R^2_{EFF})/(N-1)} \tag{23}$$

and

$$(\text{STD. ERR.})^2 = \frac{\Sigma(Y_i-\hat{Y}_i)^2}{N-1} \tag{24}$$

were used when conducting significance tests on the independent data set.

The statistics were collected and tabulated at each of the 19 prediction levels. Comparison of their values from the various estimation methods provided a means of determining whether a latitudinally dependent specification scheme over the OSV sounding samples was more effective than a composite-latitude specification scheme. After determination of a "best" scheme, specification usefulness was compared in the same manner with the WC prediction scheme. (Here WC denotes the Weinreb-Crosby regression system.)

3. Independent Data by Precipitable Water Vapor

Precipitable water vapor values, both actual and predicted, calculated by Eq. (7) were subjected to a simple linear regression of U on $\hat{U}$ by BMD03R, in order to obtain a vertically weighted comparison of the various specifications. The three statistics described in Section III.B.1 were used

to judge the effectiveness of the estimates by the various methods.

IV. STATISTICAL RESULTS

A. DEPENDENT SAMPLE

This phase of the research consisted of collecting, tabulating, and evaluating the results of three MLR tests carried out by BMDO3R on the dependent OSV-1 sample of soundings. The first MLR provided the 12 coefficients and the statistics for each of the 19 prediction equations to be applied over the composite sample of ship-soundings. The second and third MLR's provided similar sets of coefficients and statistics for the latitudinal divisions of the soundings for $\phi \geq 50N$ and $\phi < 50N$, respectively. These three sets of regression equations, employed in the form of Eq. (8), will be referred to as:

1) COEF-1 for the one over-all set, regardless of ϕ,
2) COEF-2N,S using
    a) The coefficient set COEF-2N when $\phi \geq 50N$, and
    b) COEF-2S when $\phi < 50N$,
3) The composite set of COEF-2 without the N or S designation.

The latter set implies a composite estimation by one or other of the two components of the applicable equations in the appropriate latitudinal zones. The sample size is the same as for COEF-1.

Table 5 lists the values of R_M, the standard error of estimate, and F as obtained from BMDO3R for each MLR experiment at each of the 19 levels listed in Table 2. The most

Table 5. Summary of statistics obtained during development of MLR coefficient sets COEF-1, COEF-2N, and COEF-2S by BMD03R from dependent OSV-1 sounding samples.

	COEF-1 (N=1081)			COEF-2N (N=579)			COEF-2S (N=502)		
Level	Std. Err.	R_M	F	Std. Err.	R_M	F	Std. Err.	R_M	F
1	1.22	.6508	71.40	0.86	.6212	32.40	1.52	.5781	22.40
2	1.71	.6552	73.14	1.19	.6249	33.00	2.13	.5780	22.30
3	2.68	.6557	73.30	1.86	.6263	33.30	3.33	.5780	22.30
4	3.64	.6590	74.60	2.55	.6262	33.20	4.52	.5829	22.90
5	4.74	.6605	75.20	3.34	.6262	33.30	5.88	.5862	23.30
6	6.70	.6817	84.40	4.64	.6241	32.90	8.42	.6285	29.10
7	9.45	.7074	97.40	6.12	.6346	34.80	12.18	.6579	34.00
8	16.97	.7238	106.90	9.50	.6731	42.70	22.71	.6641	35.10
9	28.15	.7021	94.50	16.39	.6875	46.20	37.28	.6430	31.40
10	37.73	.6747	81.20	22.54	.6791	44.10	49.60	.6080	26.10
11	43.77	.6489	70.70	26.73	.6709	42.20	57.25	.5709	21.50
12	64.31	.6134	58.60	40.97	.6233	32.70	82.56	.5434	18.70
13	78.80	.6214	61.10	50.74	.6477	37.30	100.67	.5600	20.30
14	91.88	.6582	74.30	64.38	.6585	39.50	112.98	.6212	28.00
15	101.74	.7018	94.30	70.95	.6888	46.50	126.53	.6503	32.60
16	101.09	.7901	161.40	72.38	.7567	69.00	125.56	.7080	44.80
17	95.08	.8666	293.10	69.55	.8157	102.50	116.98	.7769	67.80
18	84.94	.9249	575.40	59.18	.8913	199.20	104.38	.8783	150.40
19	89.27	.9409	750.70	64.01	.9066	237.80	99.46	.9250	264.00

stringent critical F-value, $F_c(k,N-k-1)$, for the entire display at the 1% significance level occurs for the degrees of freedom indicated by

$$F_c(11,490) = 2.98,$$

which occurs in the southern subdivision of OSV-1. As can be seen from Table 5, all F-values exceed this critical value by a rather impressive amount. The inference was drawn that each estimation procedure so determined was based on a strong linear dependence of W on $W_s(k)$. Additionally, comparison of the standard errors of Table 5 with the corresponding OSV-1 sample standard deviations (listed in Table 4) indicates a significant reduction of the variances by the regression estimates.

An example of a regression equation at level J=19 (corresponding to 1000 mb) is given by

$$\begin{aligned} W(19) = {} & 2.1082+0.4979\ W_s(1)-0.5900\ W_s(2)-1.1938\ W_s(3) \\ & -0.1600\ W_s(4)+0.2194\ W_s(5)-0.2095\ W_s(6)-0.1151\ W_s(7) \\ & +0.2814\ W_s(8)+0.0815\ W_s(9)+0.9076\ W_s(10)-0.0313\ W_s(11) \qquad (25) \end{aligned}$$

Equation (25) is one prediction equation of the set of 19 equations developed from COEF-1. A listing of the three coefficient sets comprising COEF-1, COEF-2(N,S) as well as the WC coefficient set is contained in Appendix A. It should be noted that the first term on the right side of (25) results from Eq. (9) with all the sample means known.

Examination of Table 5 does not reveal convincing evidence with which to determine a "best" prediction method between COEF-1 and COEF-2 as all F-values demonstrate at least a 1% significance level for dependent W-specifications. For purposes of this study, a highly significant improvement in specifications by COEF-2 over COEF-1 would be required. This requirement was deemed essential to override the added computer storage and procedures required to implement a double set of coefficients. Clearly, Table 5 does not offer this evidence.

B. INDEPENDENT SHIP SAMPLE

1. An Illustration of the Usefulness of Latitudinally-Stratified Coefficient-Set

Recall that in Section II, the question of a latitudinal stratification of the water vapor prediction equations was raised. The reason for considering this approach is well illustrated by the level-by-level results for Ship P presented in Table 6 (based here upon independent test data). The results of Table 6, e.g. larger values of R_{EFF} resulting from the COEF-2N regression scheme, indicated stronger significance level-by-level than those of either COEF-1 or COEF-2S coefficient sets when applied to the same data. These results, as much as any individual ship results, indicated the need to consider, initially, a latitudinally-stratified set of predictors, with the boundary set at $\phi \geq 50N$. In addition, COEF-1 regressions consider the alternate hypothesis, namely, the case of no latitudinal stratification.

Table 6. Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S coefficients to the 101 OSV-2 soundings from Ship P.

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R EFF	F	STD. ERR.	R EFF	F	STD. ERR.	R EFF	F
1	0.84	.5154	35.81	0.75	.6422	69.49	0.90	.4080	19.78
2	1.17	.5310	33.88	1.04	.6564	74.97	1.26	.4106	20.08
3	1.83	.5342	39.54	1.63	.6565	75.00	1.97	.4107	20.10
4	2.50	.5400	40.74	2.24	.6560	74.79	2.69	.4205	21.26
5	3.26	.5442	41.67	2.93	.6552	74.46	3.51	.4258	21.92
6	4.25	.5842	51.31	4.00	.6471	71.32	4.40	.5429	41.36
7	5.59	.6319	65.81	5.40	.6632	77.76	5.78	.5982	55.17
8	9.51	.6533	73.72	9.19	.6811	85.67	10.18	.5855	51.63
9	18.28	.5206	36.79	16.82	.6187	61.41	25.41	.0	-28.73
10	26.13	.4999	32.98	24.26	.5945	54.12	28.30	.3464	13.50
11	30.90	.5077	34.38	28.81	.5955	54.40	33.89	.3271	11.86
12	47.09	.4507	25.23	42.69	.5875	52.20	59.37	.0	-20.83
13	60.88	.3378	12.75	54.14	.5472	42.31	71.93	.0	-18.95
14	74.96	.4243	21.73	65.40	.6130	59.60	89.92	.0	-15.11
15	84.13	.4963	32.36	74.75	.6364	67.38	91.71	.3233	11.55
16	79.39	.6349	66.86	74.41	.6897	89.82	86.04	.5468	42.23
17	77.61	.6703	80.78	75.84	.6886	89.28	79.57	.6490	72.04
18	71.59	.7549	131.12	65.44	.8004	176.43	81.74	.6627	77.52
19	63.98	.7718	145.85	49.23	.8721	314.54	99.67	.1367	1.89

Note that like results for the remaining nine ships of the OSV-2 sample are listed in Appendix B in the order specified by Table 3.

2. For the Determination of a "Best" Set of Coefficients

a. Level-by-Level

Water vapor estimates were made by COEF-1 and COEF-2N,S for the entire independent OSV-2 sample. The results are to be tested level-by-level as follows:

i. COEF-1 vs. COEF-2N for latitudes $\phi \geq 50N$

ii. COEF-1 vs. COEF-2S for latitudes $\phi < 50N$

iii. COEF-1 vs. COEF-2 for all ϕ

The statistical results for the three comparisons are listed in Tables 6 through 8, respectively. As in Section IV.A the F_c value for a 1% significance level was taken for the most stringent case, i.e. case (ii) was

$$F_c(1,250) = 6.75 .$$

The summary of F-statistics in Table 7 for $\phi \geq 50N$ shows strong predictive capability at all levels in both COEF-1 and COEF-2N, with the latter demonstrating slightly higher verification (F-value) statistics. The results of COEF-2S were not as strong when compared to COEF-1. Table 8 shows slightly better verifications with COEF-1 from level 1 through 11, then a reversal for the remaining eight levels. Note that at level 9, for the COEF-2S tabulation, the value $R_{EFF}=0$, but also $F<0$. The R^2_{EFF}-value, as defined by Eq. (22) takes on negative values whenever the mean square error of

Table 7. Statistical comparison of independent data verification by COEF-1 and COEF-2N for $\phi \geq 50$.

SAMPLE SIZE = 578			COEF-1			COEF-2N		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.61	1.03	0.87	0.5255	219.819	0.84	0.5747	284.144
2	2.23	1.42	1.20	0.5314	226.658	1.15	0.5819	294.890
3	3.50	2.22	1.88	0.5320	227.374	1.81	0.5813	293.910
4	4.80	3.05	2.57	0.5348	230.679	2.48	0.5813	293.906
5	6.28	3.99	3.36	0.5370	233.436	3.24	0.5811	293.692
6	8.67	5.53	4.54	0.5705	277.906	4.51	0.5769	287.351
7	11.43	7.35	5.95	0.5880	304.371	5.97	0.5840	298.221
8	17.68	11.81	9.48	0.5967	318.415	9.35	0.6110	343.153
9	29.41	21.08	17.21	0.5774	288.045	16.85	0.6008	325.392
10	39.95	28.87	23.70	0.5710	278.581	23.34	0.5886	305.283
11	47.80	33.77	27.68	0.5731	281.678	27.29	0.5891	306.036
12	70.65	50.13	41.98	0.5464	245.142	41.12	0.5719	280.000
13	92.55	60.88	50.28	0.5639	268.561	48.89	0.5959	317.130
14	119.45	78.40	64.34	0.5713	279.120	62.27	0.6075	336.858
15	160.57	92.80	72.08	0.6299	378.909	69.76	0.6595	443.490
16	211.17	105.56	75.00	0.7037	564.956	73.03	0.7221	627.386
17	276.71	113.23	66.96	0.8064	1070.940	66.07	0.8121	1115.802
18	353.97	127.32	55.74	0.8991	2428.997	54.69	0.9031	2545.288
19	446.54	146.45	60.93	0.9093	2751.523	54.59	0.9280	3569.625

Table 8. Statistical comparison of independent data verification by COEF-1 and COEF-2S for $\phi<50$.

SAMPLE SIZE = 251			COEF-1			COEF-2S		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	2.75	1.85	1.50	0.5845	129.170	1.51	0.5731	121.787
2	3.85	2.59	2.11	0.5832	128.310	2.12	0.5736	122.082
3	6.04	4.06	3.30	0.5829	128.176	3.33	0.5733	121.946
4	8.26	5.56	4.51	0.5853	129.773	4.54	0.5782	125.060
5	10.79	7.28	5.89	0.5869	130.814	5.92	0.5813	127.103
6	15.00	10.97	8.47	0.6358	169.000	8.50	0.6319	165.548
7	20.47	16.02	12.18	0.6495	181.641	12.21	0.6474	179.623
8	34.44	29.24	22.41	0.6425	175.065	22.43	0.6415	174.130
9	57.62	49.70	38.68	0.6280	162.157	51.97	0.0	-21.258
10	75.30	62.80	50.51	0.5943	135.958	50.84	0.5871	130.961
11	86.10	69.77	56.74	0.5820	127.522	57.10	0.5746	122.763
12	121.24	95.00	80.43	0.5321	98.311	80.21	0.5357	100.242
13	154.42	117.47	97.81	0.5538	110.170	97.80	0.5540	110.252
14	199.27	140.00	113.53	0.5852	129.686	114.09	0.5796	125.917
15	261.19	164.11	124.47	0.6518	183.860	123.45	0.6589	190.998
16	355.02	172.13	120.24	0.7155	261.262	117.72	0.7296	283.417
17	496.14	177.34	108.02	0.7931	422.100	106.36	0.8002	443.176
18	629.08	207.08	100.89	0.8733	799.949	98.65	0.8793	848.282
19	767.52	250.72	101.89	0.9137	1258.659	112.39	0.8939	990.057

the estimation scheme exceeds the sample variance. For this case, the sample-mean must be taken as the best prediction scheme, and R^2_{EFF} is reset to 0 in obtaining a realistic value of R_{EFF}. However the F-value was left as calculated by Eq. (23), with k=1 and N-1 degrees of freedom. The statistical comparison of COEF-1 and COEF-2, listed in Table 9, for the entire OSV-2 independent sample was a composite of the results of Tables 7 and 8. Both estimation methods demonstrated strong prediction qualities, as evidenced by the large F-values. As in the regression analyses in Section IV.A, the comparison of the performance of COEF-1 and COEF-2, Table 9, is quite close over most of the 19 levels. Hence, there was no conclusive evidence supporting a decision to select a "best" set of coefficients from either COEF-1 or COEF-2. This decision was deferred to the outcome of the regression results relating observed to estimated values of precipitable water vapor.

b. Precipitable Water

Precipitable water calculations (U) were made on the OSV-2 sample soundings according to Eq. (7). Similar application of (7) to the 19-level OSV-2 mixing ratio specifications generated by COEF-1 and the composite set of COEF-2 equations produced two modes of estimated $\hat{U}$-values for each of the 829 soundings, depending upon the latitude of the sounding.

The simple linear regression analyses were performed on each set of U, $\hat{U}$ using BMD03R. Each regression,

Table 9. Statistical comparison of independent data verification by COEF-1 and composite COEF-2 for all ϕ.

SAMPLE SIZE = 829			COEF-1			COMPOSITE COEF-2		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.96	1.43	1.10	0.6366	563.675	1.09	0.6468	594.665
2	2.72	2.00	1.53	0.6414	578.029	1.51	0.6523	612.610
3	4.27	3.13	2.40	0.6418	579.138	2.37	0.6523	612.463
4	5.85	4.28	3.28	0.6432	583.512	3.24	0.6541	618.210
5	7.65	5.60	4.29	0.6440	586.159	4.23	0.6549	621.067
6	10.58	8.13	6.00	0.6749	691.732	6.00	0.6746	690.751
7	14.16	11.51	8.33	0.6896	750.135	8.36	0.6875	741.455
8	22.76	20.37	14.64	0.6954	774.569	14.59	0.6978	784.728
9	37.95	34.98	25.65	0.6798	710.541	31.83	0.4145	171.517
10	50.65	45.12	34.08	0.6552	622.106	34.06	0.6559	624.272
11	59.40	50.74	38.80	0.6444	587.085	38.77	0.6451	589.240
12	85.96	70.83	56.40	0.6049	477.115	55.86	0.6148	502.534
13	111.27	86.95	68.19	0.6205	517.674	67.48	0.6306	546.167
14	143.61	107.46	82.32	0.6428	582.387	81.44	0.6524	612.846
15	191.03	127.57	91.09	0.7001	794.911	89.40	0.7134	856.848
16	254.72	145.21	91.03	0.7792	1277.685	88.89	0.7908	1380.251
17	343.14	169.15	81.53	0.8761	2732.207	80.36	0.8799	2837.006
18	437.27	200.61	72.38	0.9326	5526.063	70.87	0.9355	5799.352
19	543.72	236.00	75.64	0.9473	7222.633	76.75	0.9456	6991.816

identical to the MLR with only one independent variable, was performed with U as the dependent variable and the appropriate $\hat{U}$ as the independent variable. These regressions provided significance measurements of the 19-level predictions by a single vertically-scaled F-statistic with 1 and N-2 degrees of freedom.

The statistical results from the precipitable water vapor analyses are listed in Table 10 and provided a final comparison between the COEF-1 and COEF-2 specification systems. The critical F-value,

$$F_c = 7.88$$

corresponding to the sample of N=251 soundings (ϕ<50N) provided the most stringent F-statistic significance requirements namely at the 1% level. As seen in Table 10, all calculated F-values greatly exceeded the critical value, thus indicating, to at least the 1% level of significance, that none of the specifications of precipitable water could have occurred by chance.

The precipitable water results were analogous to those in Tables 7 through 9, and as seen in Table 10, the single COEF-1 set of equations yielded the most effective specifications. Considering the conditions set down in Section IV.B.1 requiring considerably better specification by COEF-2 over COEF-1, and with the results of Sections IV.A and IV.B, the decision was made at this point to eliminate from further consideration the model of a latitudinally

differentiated set of coefficients. Thus the remainder of this research incorporated only the composite COEF-1 set of equations for comparison with the WC specification method.

Table 10. Precipitable water vapor regression statistics of U on $\hat{U}$ by COEF-1 and by the appropriate COEF-2 scheme applied to independent OSV-2 sample.

			COEF-1			COEF-2(N,S, Composite)		
AREA	MEAN	STD DEV	STD ERR	R	F	STD ERR	R	F
$\phi \geq 50$ (N=578)	.998	.408	.2344	.8191	1170.1	.2418	.8054	1063.8
$\phi < 50$ (N=251)	1.73	.674	.3847	.8218	517.9	.3902	.8161	496.4
All ϕ (N=829)	1.22	.606	.2881	.8800	2838.6	.2947	.8741	2677.2

Operational implementation of a single set of coefficients over a more complex set eliminated the requirement of additional computer core allocation for storage of a second set of coefficients and the necessary logic statements to enact the stratification differentiation. Clearly, the current results do not warrant use of the more complex COEF-2 prediction scheme.

3. Comparison With the WC Predictors

a. Level-by-Level

In this section comparison of estimates produced by the "best" COEF-1 coefficient set was made with those estimates from the WC predictions. Comparison was conducted

in accordance with the precedures discussed in Section IV.B.1.a. As in previous comparisons, the most stringent conditions were adhered to for determination of an F_c-value, in this case

$$F_c(1,250) = 6.75 .$$

Statistical comparison of the two specification methods are listed in Tables 11, 12, and 13 for the latitudinally stratified subsamples (OSV-2N, OSV-2S) and for the total OSV-2 sample, respectively.

Without exception, the COEF-1 specifications were statistically superior to those produced by the WC coefficients at all 19 J-levels in each of the three tables. The WC specifications do demonstrate considerable predictability in the lower levels of the atmosphere, however, the F-values indicate poor results in the highest two or three levels. Some possible explanations will be offered in Section V for the breakdown of the upper level specifications by the WC equations. It is clear from the results listed in Tables 11 through 13 that the COEF-1 specifications are superior to the WC predictions for the level-by-level analysis.

b. Precipitable Water

A final comparison of the WC and COEF-1 specification methods was made using precipitable water vapor calculations as in Section IV.B.1.b. Table 14 lists the statistics resulting from the vertically-scaled evaluation of the two water vapcr estimates for each of the OSV-2

Table 11. Statistical comparison of independent data verification by COEF-1 and WC for $\phi \geq 50$.

SAMPLE SIZE = 578			COEF-1			WC		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.61	1.03	0.87	0.5255	219.819	1.49	0.0	-301.142
2	2.23	1.42	1.20	0.5314	226.658	1.66	0.0	-157.119
3	3.50	2.22	1.88	0.5320	227.374	2.26	0.0	-18.481
4	4.80	3.05	2.57	0.5348	230.679	3.03	0.0889	4.566
5	6.28	3.99	3.36	0.5370	233.436	3.89	0.2216	29.733
6	8.67	5.53	4.54	0.5705	277.906	5.19	0.3453	77.936
7	11.43	7.35	5.95	0.5880	304.371	6.67	0.4215	124.494
8	17.68	11.81	9.48	0.5967	318.415	10.39	0.4753	168.134
9	29.41	21.08	17.21	0.5774	288.045	19.01	0.4319	132.087
10	39.95	28.87	23.70	0.5710	278.581	26.85	0.3677	90.027
11	47.80	33.77	27.68	0.5731	281.578	32.46	0.2768	47.778
12	70.65	50.13	41.98	0.5464	245.142	47.21	0.3362	73.410
13	92.55	60.88	50.28	0.5639	268.561	55.86	0.3976	108.170
14	119.45	78.40	64.34	0.5713	279.120	70.32	0.4422	139.983
15	160.57	92.80	72.08	0.6299	378.909	79.80	0.5106	203.067
16	211.17	105.56	75.00	0.7037	564.956	82.80	0.6203	360.276
17	276.71	113.23	66.96	0.8064	1070.940	75.68	0.7438	713.565
18	353.97	127.32	55.74	0.8991	2428.997	67.80	0.8464	1455.154
19	446.54	146.45	60.93	0.9093	2751.523	83.43	0.8219	1198.876

Table 12. Statistical comparison of independent data verification by COEF-1 and WC for $\phi<50$.

SAMPLE SIZE = 251			COEF-1			WC		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	2.75	1.85	1.50	0.5845	129.170	1.91	0.0	-15.433
2	3.85	2.59	2.11	0.5832	128.310	2.58	0.0900	2.043
3	6.04	4.06	3.30	0.5829	128.176	3.94	0.2484	16.384
4	8.26	5.56	4.51	0.5853	129.773	5.40	0.2364	14.738
5	10.79	7.28	5.89	0.5869	130.814	6.94	0.3010	24.818
6	15.00	10.97	8.47	0.6358	169.000	9.76	0.4576	65.931
7	20.47	16.02	12.18	0.6495	181.641	13.77	0.5116	88.281
8	34.44	29.24	22.41	0.6425	175.065	24.99	0.5194	92.007
9	57.62	49.70	38.68	0.6280	162.157	43.76	0.4743	72.285
10	75.30	62.80	50.51	0.5943	135.958	56.00	0.4525	64.125
11	85.10	69.77	56.74	0.5820	127.522	63.94	0.4000	47.431
12	121.24	95.00	80.43	0.5321	98.311	89.10	0.3467	34.013
13	154.42	117.47	97.81	0.5538	110.170	108.46	0.3841	43.085
14	199.27	140.00	113.53	0.5852	129.686	124.20	0.4615	67.400
15	261.19	164.11	124.47	0.6518	183.860	135.29	0.5660	117.363
16	355.02	172.13	120.24	0.7155	261.262	130.43	0.6525	184.680
17	496.14	177.34	108.02	0.7931	422.100	121.21	0.7299	284.018
18	629.08	207.08	100.89	0.8733	799.949	113.23	0.8373	583.856
19	767.52	250.72	101.89	0.9137	1258.659	118.41	0.8815	867.412

Table 13. Statistical comparison of independent data verification by COEF-1 and WC for all ϕ.

SAMPLE SIZE = 829			COEF-1			WC		
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.96	1.43	1.10	0.6366	563.675	1.63	0.0	-189.437
2	2.72	2.00	1.53	0.6414	578.029	1.98	0.1049	9.219
3	4.27	3.13	2.40	0.6418	579.138	2.87	0.3990	156.566
4	5.85	4.28	3.28	0.6432	583.512	3.90	0.4119	169.006
5	7.65	5.60	4.29	0.6440	586.159	5.01	0.4483	208.039
6	10.58	8.13	6.00	0.6749	691.732	6.89	0.5309	324.675
7	14.16	11.51	8.33	0.6896	750.135	9.39	0.5781	415.186
8	22.76	20.37	14.64	0.6954	774.569	16.24	0.6034	473.598
9	37.95	34.93	25.65	0.6798	710.541	28.81	0.5672	392.229
10	50.65	45.12	34.08	0.6552	622.106	38.07	0.5367	334.697
11	59.40	50.74	38.80	0.6444	587.085	44.37	0.4852	254.663
12	85.96	70.83	56.40	0.6049	477.115	62.85	0.4611	223.352
13	111.27	86.95	68.19	0.6205	517.674	75.67	0.4925	264.897
14	143.61	107.46	82.32	0.6428	582.387	90.02	0.5462	351.625
15	191.03	127.57	91.09	0.7001	794.911	99.82	0.6227	523.701
16	254.72	145.21	91.03	0.7792	1277.685	99.57	0.7279	932.076
17	343.14	169.15	81.53	0.8761	2732.207	91.80	0.8399	1980.926
18	437.27	200.61	72.38	0.9326	5526.063	84.11	0.9079	3877.568
19	543.72	236.00	75.64	0.9473	7222.633	95.31	0.9148	4243.453

stratifications. The statistics were generated from two simple linear regressions by BMD03R of U on each of the $\hat{U}$-estimates. The last line of Table 14 indicates a definite superiority of the COEF-1 equations over the WC equations for the independent OSV-2 data sample.

Table 14. Precipitable water vapor results by COEF-1 and modified WC coefficients applied to independent OSV-2 sample.

			COEF-1			WC		
AREA	MEAN	STD DEV	STD ERR	R	F	STD ERR	R	F
$\phi \geq 50$ (N=578)	.998	.408	.2344	.8191	1170.1	.2658	.7587	781.1
$\phi < 50$ (N=251)	1.73	.674	.3847	.8218	517.9	.5324	.7297	283.5
All ϕ (N=829)	1.22	.606	.2881	.8800	2838.6	.3393	.8289	1816.1

C. ISLAND AND COASTAL (NESS) DATA

1. Level-by-Level

The 160 NESS island and coastal March soundings provided a test sample that focussed, to a degree, on evaluation of the possible significance of winter effects on W-profile. Table 15 presents the statistics obtained by the first efforts at estimating the W-profiles by COEF-1 and WC coefficients. In making these first W-specifications all 160 soundings (with observed W-values up to at least 510 mb) were accepted as valid data. The results presented in Table 15 were at best discouraging for both sets of coefficients.

Table 15. Statistical comparison of COEF-1 and WC coefficients applied to the 160 NESS soundings.

			COEF-1			WC			
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	SAMPLE SIZE
1	14.17	4.11	14.74	0.0	-6.457	12.95	0.0	-6.296	9
2	12.41	3.42	12.39	0.0	-7.392	10.74	0.0	-7.191	10
3	9.53	3.25	8.83	0.0	-10.377	7.53	0.0	-9.766	14
4	11.62	7.30	7.77	0.0	-3.468	13.17	0.0	-20.772	32
5	15.64	10.96	9.52	0.4954	17.890	19.27	0.0	-37.210	57
6	20.22	18.56	16.71	0.4358	17.814	26.31	0.0	-38.152	78
7	23.91	20.77	21.96	0.0	-9.913	25.44	0.0	-31.326	96
8	32.78	31.72	44.16	0.0	-69.690	34.38	0.0	-21.359	146
9	52.70	53.50	72.49	0.0	-70.132	56.33	0.0	-15.104	156
10	64.29	66.64	92.35	0.0	-75.708	64.45	0.2546	10.957	160
11	79.74	81.45	96.96	0.0	-46.502	78.22	0.2787	13.320	160
12	102.53	96.53	115.48	0.0	-47.592	94.74	0.1916	6.026	160
13	131.05	121.40	146.19	0.0	-49.035	118.02	0.2343	9.171	160
14	175.19	165.14	150.99	0.4050	31.005	148.26	0.4405	38.034	160
15	223.14	194.53	191.61	0.1726	4.854	161.49	0.5576	71.286	160
16	323.27	264.43	224.08	0.5309	62.032	181.43	0.7275	177.647	160
17	477.09	379.90	200.03	0.8502	411.888	168.10	0.8968	648.994	160
18	589.84	455.04	193.17	0.9054	718.771	167.76	0.9296	1004.475	160
19	702.71	522.26	226.88	0.9007	679.219	191.62	0.9303	1015.678	160

The negative F-values, starting at level 13 for the COEF-1 specifications and at level 9 for those by the WC method, indicated considerably greater effectiveness would be achieved by making predictions with the sample mean values of the mixing ratios.

It was noted that a number of the NESS soundings should not have been considered reliable after reviewing the actual W-profiles. Unreliable soundings were identified when the reported moisture profiles indicated RH<20% in the lower levels of the soundings and persisted with increasing ascent. It was felt that the low moisture reports were due mostly to a failure of the moisture element on the radiosonde instrument.

If a sounding had RH considerably higher than 20% at all levels, its moisture profile was considered reliable and the sounding was retained. In some cases the relative humidity decreased to values lower than 20% in the mid-troposphere but then recovered to exceed 20% at higher levels. Such soundings were also retained in a revised test set. If the RH persisted at less than 20% throughout most of the troposphere, including the upper regions where motor-boating is not infrequent, the sounding was considered unreliable and discarded (see Table 16).

Table 16. Examples of three types of soundings categorized by RH profiles extending up to level 10 and considered for possible inclusion in the NESS sample.

Level	Reliable	(% RH) Recovered	Unreliable
10	72	71	15
11	67	63	16
12	62	23	16
13	45	11	17
14	42	9	18
15	43	11	21
16	42	16	20
17	37	31	18
18	57	29	67
19	79	38	76

After screening the NESS soundings using the method of Table 16, a total of 124 soundings remained for testing. Table 17 lists the statistical results of the level-by-level W-specifications by the COEF-1 and WC equation sets. Since the number of soundings with observed W-values drop off sharply above level 10, the critical F-value was arbitrarily taken for N=70 occurring at level 7 and

$$F_c = 7.01.$$

This value of F_c is considerably more stringent than necessary for specifications at levels below level J=7, but as Table 17 demonstrates, this is a reasonable restriction.

Table 17. Statistical comparison of COEF-1 and WC coefficients applied to the 124 NESS soundings.

			COEF-1			WC			
LEVEL	MEAN	STD. DEV.	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	SAMPLE SIZE
1	14.17	4.11	14.74	0.0	-6.457	12.95	0.0	-6.296	9
2	12.41	3.42	12.39	0.0	-7.392	10.74	0.0	-7.191	10
3	9.63	3.36	9.02	0.0	-9.473	7.57	0.0	-8.835	13
4	12.24	9.16	7.87	0.5116	6.381	13.94	0.0	-10.217	20
5	16.16	12.95	10.00	0.6347	24.958	20.09	0.0	-21.632	39
6	20.41	19.95	15.89	0.6046	30.537	26.90	0.0	-23.855	55
7	24.52	22.66	16.62	0.6799	58.463	27.16	0.0	-20.656	70
8	33.71	33.94	31.89	0.3421	14.446	36.26	0.0	-13.500	111
9	56.44	58.87	49.46	0.5425	49.615	61.45	0.0	-9.785	121
10	69.48	73.63	64.55	0.4810	36.739	69.02	0.3484	16.850	124
11	85.48	89.83	72.08	0.5967	67.455	81.17	0.4283	27.402	124
12	108.50	104.52	88.23	0.5361	49.206	98.64	0.3306	14.971	124
13	138.30	131.21	112.99	0.5083	42.501	123.95	0.3279	14.697	124
14	171.96	159.88	127.65	0.6021	69.384	141.10	0.4703	34.654	124
15	213.22	185.48	150.69	0.5830	62.832	145.28	0.6217	76.872	124
16	290.31	240.55	171.17	0.7026	118.959	143.25	0.8034	222.040	124
17	414.62	347.11	157.50	0.8911	470.588	141.34	0.9133	613.827	124
18	512.75	419.46	155.55	0.9287	765.188	138.53	0.9439	996.483	124
19	613.24	479.93	187.13	0.9209	680.516	165.09	0.9390	909.010	124

Examination of the F-values of Table 17 indicated that the WC coefficients performed more effectively in the lower levels of the atmosphere. Above level 16, the COEF-1 set of equations produced statistically superior estimates up to level 4, where both estimation procedures produce negative R^2_{EFF} and F-values. The small number of soundings containing data in the last four levels was considered responsible for these unusual statistical outcomes and it was impossible to draw any useful conclusion regarding the comparative upper-level specificity by the two estimation systems.

2. Precipitable Water Vapor

Precipitable water vapor integrations were performed using Eq. (7) on each of the 124 NESS soundings, incorporating all available J-levels for which mixing ratio values existed, $J \leq 9$. Additionally, $\hat{U}$-values were calculated using only the corresponding levels for the associated $\hat{U}$-integrations up to level J.

The statistical results, as produced by a BMD03R simple linear regression of U on each of the two $\hat{U}$'s, are displayed in Table 18.

Table 18. Statistical results from BMD03R simple linear regressions on precipitable water vapor calculations obtained from the 124 NESS observed and COEF-1, WC-estimated mixing ratio-values.

		COEF-1			WC		
MEAN	STD DEV	STD ERR	R	F	STD ERR	R	F
1.44	1.1	.4292	.9218	690.1	.4850	.8990	514.0

The critical F-value

$$F_c(1,122) = 6.84$$

was compared to the calculated F-values of Table 18 to evaluate the significance of the vertically scaled mixing ratio specifications. It was readily apparent that the U-estimates both by the COEF-1 and WC systems demonstrated high statistical significance and that the COEF-1 estimates indicated somewhat higher predictability.

Reviewing the results of Table 18 along with those of Table 17, it became obvious that the near-surface mixing ratio values dominate the precipitable water vapor integration, and that the upper level breakdown of the WC specifications, as evidenced by Table 17, was masked by this dominance. Note that the W-values of the dependent and independent OSV data sets were determined by Smith's power law, Eq. (6), for levels above J=9. On the other hand, the W-values for the NESS data set were taken solely as indicated by the radiosonde instrument, as were the data used by WC in determining their regression coefficients. Application of the power law to the OSV data tended to smooth the W-profile at higher levels and yielded a degree of consistency in the OSV W-profiles in the highest 5 prediction levels ($P \leq 300$ mb), giving small $\overline{W}$-values over the OSV's at levels higher than J=5 as compared with those resulting from the NESS sounding samples (Table 17). It is felt that the high values of $\overline{W}$ in the NESS data could be attributed largely to inaccuracies in the radiosonde observational data at the higher levels.

V. CONCLUSIONS

This thesis has reinforced the findings of Weinreb and Crosby (WC) in providing supporting evidence that mixing ratios can be described by a linear combination of a designated 11-element temperature T(P)-profile, which is equivalent to a profile of $W_s(P)$. Further, it has been shown that any dependence of the relationship between temperature and mixing ratio on latitude is insignificant, and that one single set of specification equations can be employed over all latitudes.

It was evident from the statistical results presented in Section IV.B.2 that the performance of the coefficient set (COEF-1) was superior to that of the WC coefficient set over the Ocean Station Vessels. However, the causes of the improved specifications were not regarded as a result of a land-mass (coastal) or seasonal effect. Rather, inaccuracies inherent in radiosonde moisture data in the higher level atmospheric structure may have affected the definition of the WC coefficients, which were derived by moisture data of accuracy comparable to that of the NESS data. This reasoning is supported by the independent tests of the COEF-1 and WC specifications on the NESS data.

Efforts to produce an accurate prediction scheme by MLR techniques, as demonstrated by this work, appear extremely promising. Effective prediction procedures seem not to be associated with seasonal, latitudinal or land-mass (coastal)

effects. Rather, effective prediction appears to depend upon an accurate data base of sufficiently good quality from which to define accurate coefficient sets over the depth 1000-200 mb. The results of this research indicate that the OSV data provide such a data base, and that mixing ratio estimates by a set of equations of the form derived here provide a representative profile of W(P) up to approximately 200 mb. The high level of predictability of the precipitable water vapor resulting from the vertical integration of mixing ratio estimates provided substantial evidence supporting the conclusion that the OSV data define highly effective regression equations.

APPENDIX A

This Appendix contains a listing of the three sets of regression coefficients COEF-1, COEF-2N, and COEF-2S determined by BMD03R from the OSV-1 ship sample. A fourth listing contains the selection of coefficients extracted from the WC set described in Section I.

Each of the four sets of coefficients was applied according to the following matrix operation to produce the appropriate mixing ratio estimates at level J:

$$\left| A_J, C_{J1}, C_{J2}, \ldots, C_{J11} \right| \cdot \left| \begin{array}{c} 1 \\ W_s(1) \\ W_s(2) \\ \vdots \\ W_s(11) \end{array} \right| = \left| W_J \right|$$

$J = 1, \ldots, 19$

APPENDIX A-1: The coefficient-set (COEF-1) derived from the dependent set of Janaury ship-soundings, over all ϕ, and covering estimations at 19 mixing ratio prediction levels.

LEVEL	A	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
1	1.0026	-0.0212	-0.0009	0.0253	0.0203	-0.0031	-0.0024	0.0023	-0.0001	-0.0012	0.0052	-0.0032
2	1.3296	-0.0284	-0.0010	0.0349	0.0290	-0.0043	-0.0036	0.0035	-0.0003	-0.0016	0.0070	-0.0043
3	2.0541	-0.0423	-0.0033	0.0551	0.0456	-0.0068	-0.0056	0.0055	-0.0006	-0.0025	0.0109	-0.0068
4	2.8444	-0.0465	-0.0282	0.0816	0.0632	-0.0095	-0.0077	0.0073	-0.0005	-0.0036	0.0152	-0.0094
5	3.7476	-0.0485	-0.0616	0.1134	0.0826	-0.0121	-0.0101	0.0094	-0.0004	-0.0049	0.0200	-0.0124
6	4.5303	-0.0129	-0.1140	0.0800	0.1553	-0.0143	-0.0172	0.0098	0.0059	-0.0083	0.0257	-0.0167
7	4.5653	0.0126	-0.1455	0.0161	0.2642	-0.0207	-0.0272	0.0102	0.0130	-0.0121	0.0359	-0.0229
8	3.8273	-0.0100	-0.0945	-0.1737	0.5439	-0.0392	-0.0585	0.0112	0.0344	-0.0278	0.0744	-0.0435
9	8.3158	-0.0330	0.0451	-0.3978	0.7773	0.0266	-0.1389	0.0410	0.0669	-0.0682	0.1549	-0.0917
10	11.0248	-0.0131	0.1806	-0.4934	0.6841	0.2009	-0.2092	0.0870	0.0561	-0.0729	0.2186	-0.1351
11	14.1071	-0.1368	0.3274	-0.4419	0.4279	0.3515	-0.2270	0.0832	0.0508	-0.0478	0.2436	-0.1586
12	16.6918	0.2152	-0.1064	-0.3085	0.2567	0.4065	-0.2307	0.0591	0.0800	0.0294	0.2979	-0.2191
13	21.5908	-0.0987	0.5138	-0.5974	0.2466	0.4098	-0.3295	0.0778	0.1363	0.0402	0.4569	-0.3200
14	22.3586	0.5455	-0.6588	-0.0700	0.0432	0.4991	-0.4586	0.0200	0.1994	0.1509	0.5976	-0.4171
15	17.7069	0.9448	-1.1365	-0.2174	0.1562	0.4207	-0.1834	-0.5249	0.3853	0.1405	0.7943	-0.4359
16	6.0505	1.1031	-1.1792	-0.4577	0.1669	0.2938	0.0252	-0.1585	-0.4410	0.3959	1.0113	-0.4377
17	-2.1257	0.8382	-0.6289	-1.0723	0.3774	0.1448	-0.0392	0.0169	-0.0710	-0.3449	1.4459	-0.4182
18	1.9780	0.7892	-1.1843	-0.8420	-0.1108	0.3683	-0.1523	0.0218	0.1913	-0.1118	1.0145	-0.2112
19	2.1081	0.4979	-0.5900	-1.1938	-0.1600	0.2193	-0.2095	-0.1151	0.2814	0.0815	0.9076	-0.0313

APPENDIX A-2: The coefficient set (COEF-2N) derived from the dependent set of January ship-soundings, for $\phi \geq 50N$, and covering estimates at 19 mixing ratio prediction levels.

LEVEL	A	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
1	0.4227	0.0025	0.0055	-0.0307	0.0376	0.0019	0.0001	-0.0024	-0.0001	-0.0005	0.0049	-0.0027
2	0.5184	0.0054	0.0086	-0.0450	0.0542	0.0023	-0.0002	-0.0028	-0.0006	-0.0004	0.0064	-0.0034
3	0.8064	0.0081	0.0162	-0.0725	0.0856	0.0038	-0.0002	-0.0043	-0.0012	-0.0004	0.0099	-0.0054
4	1.1299	0.0113	0.0216	-0.0988	0.1168	0.0053	-0.0002	-0.0060	-0.0016	-0.0005	0.0137	-0.0075
5	1.5053	0.0149	0.0276	-0.1287	0.1525	0.0071	-0.0002	-0.0079	-0.0020	-0.0008	0.0180	-0.0100
6	1.7595	0.0032	0.0585	-0.1828	0.2095	0.0103	0.0007	-0.0137	-0.0013	-0.0018	0.0250	-0.0126
7	2.0793	0.0196	0.0571	-0.2313	0.2859	0.0112	-0.0011	-0.0150	-0.0022	-0.0031	0.0346	-0.0179
8	1.8009	0.1560	-0.0558	-0.3177	0.4551	0.0265	-0.0150	-0.0063	-0.0009	-0.0114	0.0535	-0.0367
9	-1.5910	0.4224	-0.1262	-0.6817	0.5713	0.1678	-0.0414	0.0056	0.0080	-0.0417	0.1302	-0.0705
10	-3.4356	0.6964	-0.1287	-1.0765	0.5203	0.3348	-0.0662	0.0368	-0.0020	-0.0700	0.2005	-0.1065
11	-4.3413	0.8149	-0.1021	-1.2572	0.4045	0.4282	-0.0734	0.0360	0.0184	-0.0900	0.2489	-0.1315
12	-3.9722	1.2401	0.1091	-2.1463	0.1445	0.6145	-0.0709	0.0902	-0.0086	-0.0795	0.3138	-0.1694
13	-8.3489	1.5591	0.5180	-3.0241	0.3293	0.5685	-0.0268	0.0759	-0.0499	-0.0164	0.4216	-0.2370
14	-22.5987	2.2995	0.0816	-3.1096	0.4501	0.6237	-0.1408	0.1901	-0.1182	0.0307	0.5529	-0.3036
15	-32.0117	2.2128	0.4015	-3.7245	0.9238	0.3138	0.0598	-0.2740	0.1691	-0.0430	0.7371	-0.3008
16	-34.6418	1.5640	0.9914	-3.7935	1.3043	-0.0835	0.0715	-0.0089	-0.3520	0.3171	0.7529	-0.2565
17	-27.5513	1.5835	0.6421	-3.1845	1.0021	0.0027	0.0234	-0.0135	-0.1703	0.1304	0.9012	-0.2194
18	-35.5193	1.1660	0.7112	-2.4048	0.3522	0.1571	-0.0845	0.0449	0.0465	0.0738	0.7196	0.0198
19	-51.8142	0.3534	2.0738	-2.9448	0.4936	-0.0262	-0.2046	0.1377	0.0444	0.2038	0.3764	0.4341

APPENDIX A-3: The coefficient set (COEF-2S) derived from the dependent set of January ship-soundings, for $\phi<50N$, and covering estimations at 19 mixing ratio prediction levels.

LEVEL	A	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
1	1.1141	-0.0229	0.0055	0.0258	0.0213	-0.0060	-0.0034	0.0034	0.0005	-0.0014	0.0052	-0.0034
2	1.5620	-0.0322	0.0078	0.0361	0.0300	-0.0084	-0.0047	0.0047	0.0007	-0.0019	0.0073	-0.0047
3	2.4488	-0.0507	0.0125	0.0564	0.0470	-0.0131	-0.0075	0.0074	0.0011	-0.0030	0.0114	-0.0074
4	3.5005	-0.0644	-0.0106	0.0869	0.0636	-0.0172	-0.0103	0.0097	0.0019	-0.0043	0.0157	-0.0101
5	4.7192	-0.0795	-0.0411	0.1229	0.0827	-0.0221	-0.0135	0.0122	0.0028	-0.0059	0.0205	-0.0131
6	5.0685	-0.0611	-0.0967	0.0975	0.1574	-0.0249	-0.0226	0.0144	0.0097	-0.0083	0.0245	-0.0169
7	5.2512	-0.1167	-0.0914	0.0329	0.2660	-0.0318	-0.0357	0.0155	0.0187	-0.0118	0.0355	-0.0238
8	6.7856	-0.3990	0.1236	-0.1938	0.5582	-0.0598	-0.0763	0.0156	0.0474	-0.0287	0.0801	-0.0477
9	13.5063	-0.3569	0.2946	0.4434	0.8532	-0.0240	-0.1747	0.0547	0.0862	-0.0696	0.1594	-0.0976
10	19.7938	-0.2971	0.4672	-0.5439	0.7806	0.1422	-0.2609	0.1088	0.0779	-0.0681	0.2299	-0.1536
11	27.7579	-0.5552	0.7067	-0.4925	0.5153	0.2978	-0.2810	0.1038	0.0677	-0.0304	0.2522	-0.1831
12	57.4507	-0.6441	0.4775	-0.2776	0.3628	0.3100	-0.3047	0.0796	0.1171	0.0723	0.3800	-0.3394
13	55.9326	-1.3594	1.4026	-0.5712	0.3225	0.3187	-0.4567	0.1119	0.2073	0.0656	0.5564	-0.4385
14	72.8999	-1.3953	0.4652	0.0403	0.0522	0.3919	-0.6200	0.0290	0.3162	0.1920	0.7373	-0.5800
15	45.3192	-0.1440	-0.6704	0.0614	0.1229	0.3910	-0.3093	-0.5300	0.4479	0.1884	0.9176	-0.5627
16	39.1055	0.7480	-1.4555	0.0026	0.0263	0.3800	0.0118	-0.1981	-0.4546	0.3921	1.1981	-0.5873
17	13.0671	-0.5028	-0.3777	-0.8414	0.2436	0.2202	-0.0444	-0.0377	-0.0122	-0.5154	1.6174	-0.4560
18	-12.3491	-2.4390	0.1314	-0.5068	-0.3827	0.4918	-0.1542	-0.0039	0.1952	-0.1271	1.1293	-0.2642
19	-119.3171	-1.2744	0.2741	-0.6125	-0.5199	0.3981	-0.2523	0.0509	0.2108	0.0896	1.1704	-0.1299

APPENDIX A-4: The set of coefficients extracted for the WC coefficients and used for comparative testing.

LEVEL	A	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
1	-40.9630	2.5560	-2.3200	0.6851	0.3864	-0.1562	-0.2134	0.0297	-0.0059	0.3937	0.2124	0.3906
2	-26.4402	1.9690	-1.1420	0.0251	0.5233	0.0118	-0.0597	0.0149	-0.0504	0.3010	0.1926	0.2623
3	2.6406	2.0660	-2.4230	0.9983	0.3731	0.1955	-0.1432	0.0309	-0.1095	-0.1405	0.6751	0.0521
4	12.6899	3.2000	-4.6990	2.4060	0.4207	0.1413	-0.0423	-0.2532	-0.5770	0.7065	0.3802	-0.0396
5	22.9585	3.4610	-5.4630	3.2070	0.5598	-0.0666	-0.2672	-0.5898	0.2866	0.3921	0.3132	-0.1022
6	19.0578	3.3160	-5.1620	2.7370	0.8039	-0.1767	-0.6590	0.0919	0.1773	0.2443	0.2568	-0.1327
7	15.8943	2.3720	-3.7320	2.5140	0.7542	-0.3632	-0.3732	0.0682	0.1275	0.1755	0.1919	-0.1233
8	17.1051	1.6920	-2.9420	2.0020	0.8106	-0.4303	-0.2243	0.0411	0.0785	0.1660	0.0973	-0.0798
9	13.8295	0.9962	-1.9250	1.3740	0.6693	-0.3001	-0.1948	0.0216	0.1049	0.1034	0.0776	-0.0641
10	13.2890	0.8519	-1.8210	1.2230	0.6163	-0.2602	-0.1285	0.0074	0.0743	0.0795	0.0520	-0.0625
11	9.3732	0.8027	-1.7730	1.2470	0.2776	-0.1253	-0.0927	0.0175	0.0585	0.0612	0.0272	-0.0423
12	7.1461	0.4153	-1.0870	0.8930	0.1582	-0.0622	-0.0470	0.0124	0.0314	0.0415	0.0154	-0.0364
13	5.0865	0.2217	-0.6398	0.6171	0.1212	-0.0502	-0.0325	0.0111	0.0223	0.0274	-0.0023	-0.0186
14	4.1636	0.1545	-0.4538	0.5149	0.0630	-0.0352	-0.0173	0.0068	0.0143	0.0157	0.0014	-0.0152
15	3.4746	0.0740	-0.2222	0.3598	0.0240	-0.0223	-0.0094	0.0034	0.0091	0.0054	0.0048	-0.0107
16	2.8706	0.0353	-0.1006	0.2432	0.0191	-0.0200	-0.0054	0.0031	0.0056	0.0029	0.0055	-0.0089
17	2.0860	0.0431	-0.0300	0.1378	0.0166	-0.0144	-0.0025	0.0016	0.0039	0.0013	0.0056	-0.0073
18	0.9920	0.1843	-0.1510	0.1140	0.0120	-0.0079	-0.0017	0.0015	0.0027	0.0005	0.0036	-0.0053
19	0.8860	0.2375	-0.2180	0.1103	0.0088	-0.0047	-0.0011	0.0014	0.0018	0.0002	0.0028	-0.0046

APPENDIX B

Appendix B lists the level-by-level statistical results obtained by application of coefficient sets COEF-1, COEF-2N, and COEF-2S to the individual OSV-2 soundings. The listings are arranged in the order specified by Table 3, only that Ship Station P is not included here (see Table 6).

APPENDIX B-1: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship A (N=97).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	0.76	.6113	56.69	0.74	.6447	67.58	0.78	.5790	47.91
2	1.04	.6161	58.13	1.01	.6474	68.53	1.08	.5772	47.47
3	1.63	.6162	58.16	1.58	.6447	67.57	1.69	.5772	47.47
4	2.23	.6194	59.14	2.17	.6444	67.49	2.30	.5849	49.39
5	2.91	.6220	59.95	2.84	.6444	67.46	3.00	.5888	50.41
6	3.99	.6454	67.84	4.02	.6391	65.62	3.99	.6447	67.57
7	5.12	.6645	75.14	5.25	.6434	67.09	5.17	.6564	71.91
8	7.43	.7050	94.41	7.64	.6846	83.82	7.58	.6909	86.76
9	12.65	.7292	107.89	12.68	.7277	106.90	16.87	.4079	18.96
10	16.15	.7464	119.50	16.32	.7399	114.88	17.23	.7041	93.37
11	18.56	.7490	121.40	18.75	.7430	117.10	20.27	.6904	86.54
12	29.68	.7040	93.34	30.62	.6806	81.97	37.49	.4420	23.07
13	34.76	.7396	114.69	37.29	.6919	87.24	38.65	.6632	74.60
14	44.61	.7299	108.35	47.00	.6938	88.18	50.54	.6327	63.42
15	49.30	.7649	133.90	50.84	.7473	120.20	48.56	.7729	140.88
16	61.48	.7459	119.09	60.27	.7573	127.75	60.50	.7552	126.07
17	50.59	.8543	256.56	50.86	.8526	252.80	50.11	.8573	263.32
18	37.63	.9297	605.51	39.21	.9235	550.29	53.78	.8503	247.95
19	51.53	.8935	376.04	48.53	.9061	436.15	95.13	.5591	43.21

APPENDIX B-2: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship B (N=77).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	0.75	.5448	31.66	0.69	.6298	49.30	0.76	.5207	27.89
2	1.06	.5348	30.05	0.98	.6238	47.76	1.07	.5206	27.88
3	1.66	.5343	29.97	1.54	.6236	47.72	1.68	.5203	27.84
4	2.27	.5379	30.53	2.10	.6246	47.98	2.29	.5250	28.53
5	2.97	.5409	31.02	2.75	.6253	48.15	3.00	.5263	28.74
6	3.83	.5929	40.65	3.71	.6265	48.46	3.91	.5707	36.22
7	5.07	.6204	46.93	4.96	.6405	52.18	5.28	.5752	37.07
8	8.60	.6558	56.59	8.30	.6850	66.30	9.05	.6071	43.79
9	15.41	.6610	58.18	14.76	.6950	70.07	17.34	.5356	30.17
10	22.41	.6323	49.96	21.66	.6631	58.85	22.52	.6276	48.74
11	26.55	.6334	50.25	25.94	.6544	56.19	26.54	.6337	50.33
12	42.93	.5645	35.08	42.76	.5694	35.98	44.65	.5127	26.75
13	53.69	.5274	28.89	52.62	.5536	33.14	55.54	.4769	22.08
14	65.93	.5962	41.35	66.32	.5897	39.97	67.08	.5767	37.38
15	79.81	.6097	44.37	81.09	.5928	40.63	77.58	.6374	51.33
16	76.74	.7344	87.83	78.36	.7210	81.18	70.53	.7816	117.77
17	71.94	.7799	116.44	68.42	.8035	136.64	74.28	.7631	104.56
18	39.80	.9309	486.89	44.05	.9146	383.70	58.69	.8424	183.32
19	48.96	.8887	281.70	42.90	.9157	389.54	95.89	.4398	17.98

APPENDIX B-3: Verification statistics resulting from application of COEF-1, COEF-2N, and and COEF-2S to OSV-2 soundings from Ship C (N=94).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	0.81	.4274	20.57	0.83	.3775	15.29	0.86	.3110	9.84
2	1.13	.4557	24.12	1.15	.4214	19.87	1.20	.3165	10.25
3	1.76	.4599	24.67	1.79	.4251	20.29	1.88	.3169	10.26
4	2.42	.4584	24.47	2.46	.4258	20.38	2.58	.3098	9.77
5	3.16	.4571	24.30	3.22	.4251	20.29	3.39	.3043	9.39
6	4.27	.4562	24.18	4.48	.3592	13.63	4.33	.4310	21.00
7	5.75	.4559	24.13	5.95	.3894	16.43	5.81	.4377	21.81
8	9.52	.4497	23.31	9.45	.4630	25.11	10.02	.3400	12.03
9	17.51	.4518	23.60	18.00	.3987	17.39	25.26	.0	-36.46
10	24.42	.4927	29.50	25.48	.4188	19.57	25.75	.3970	17.21
11	28.13	.5049	31.48	29.47	.4267	20.49	30.05	.3870	16.21
12	42.76	.5230	34.64	43.85	.4858	28.42	50.15	.0245	0.06
13	48.67	.6316	61.05	51.66	.5680	43.81	53.55	.5218	34.43
14	66.75	.6206	57.62	70.95	.5526	40.44	72.63	.5216	34.39
15	76.88	.6611	71.41	81.21	.6097	54.44	77.79	.6508	67.59
16	71.69	.7647	129.51	75.44	.7349	108.04	72.89	.7554	122.30
17	58.71	.8691	284.08	60.19	.8619	265.88	59.09	.8673	279.31
18	59.67	.9017	399.93	63.29	.8886	345.21	62.05	.8932	362.91
19	58.99	.8958	373.69	63.57	.8778	309.07	70.77	.8460	231.61

APPENDIX B-4: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship I (N=106).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	0.87	.5322	41.09	0.85	.5628	48.19	0.90	.4875	32.42
2	1.16	.5376	42.27	1.14	.5685	49.66	1.21	.4790	30.95
3	1.83	.5351	41.72	1.78	.5658	48.96	1.91	.4727	29.92
4	2.50	.5376	42.27	2.45	.5658	48.96	2.61	.4762	30.51
5	3.27	.5396	42.72	3.20	.5660	49.01	3.41	.4785	30.89
6	4.46	.5754	51.48	4.48	.5696	49.93	4.47	.5732	50.90
7	5.81	.5840	53.81	5.89	.5684	49.65	5.83	.5816	53.16
8	8.95	.5796	52.60	8.90	.5858	54.35	9.28	.5361	41.93
9	16.04	.6002	58.57	15.85	.6128	62.52	22.06	.0	-18.06
10	21.22	.6094	61.43	21.17	.6117	62.19	22.21	.5579	47.00
11	24.02	.6223	65.74	24.07	.6202	65.01	25.41	.5607	47.70
12	34.18	.6258	66.95	34.16	.6265	67.18	40.47	.3842	18.00
13	41.09	.6428	73.23	40.46	.6565	78.78	45.31	.5352	41.73
14	54.03	.6184	64.40	52.97	.6375	71.20	61.22	.4552	27.19
15	57.96	.6583	79.57	54.46	.7070	103.93	61.29	.6055	60.19
16	67.27	.6759	87.45	62.53	.7284	117.54	71.68	.6190	64.61
17	64.17	.7596	141.85	61.48	.7820	163.79	67.22	.7320	120.06
18	59.74	.8352	239.82	54.20	.8666	313.75	69.00	.7723	153.77
19	71.73	.8326	235.06	59.94	.8865	381.48	98.31	.6510	76.48

APPENDIX B-5: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship J (N=103).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.13	.4781	29.93	1.10	.5272	38.86	1.16	.4319	23.16
2	1.55	.4823	30.61	1.50	.5302	39.49	1.60	.4279	22.64
3	2.43	.4830	30.73	2.36	.5300	39.46	2.51	.4279	22.64
4	3.33	.4856	31.17	3.23	.5299	39.44	3.43	.4343	23.47
5	4.35	.4877	31.52	4.23	.5296	39.38	4.48	.4382	23.99
6	5.98	.5218	37.80	5.93	.5329	40.05	6.06	.5037	34.34
7	7.79	.5321	39.89	7.79	.5325	39.99	7.95	.5040	34.39
8	12.13	.5032	34.24	11.92	.5280	39.04	12.73	.4212	21.78
9	21.82	.4831	30.75	21.47	.5074	35.03	26.04	.0	-8.51
10	29.71	.4468	25.19	29.19	.4769	29.73	30.69	.3816	17.21
11	35.12	.4148	21.00	34.35	.4561	26.53	36.27	.3421	13.38
12	52.19	.3571	14.76	50.79	.4170	21.26	56.94	.0	-3.74
13	59.04	.3740	16.42	56.21	.4694	28.53	64.18	.0	-1.64
14	75.71	.3273	12.11	70.08	.4848	31.03	84.87	.0	-10.98
15	81.05	.4749	29.41	75.17	.5778	50.62	86.49	.3435	13.52
16	91.41	.5212	37.69	86.82	.5857	52.74	96.30	.4379	23.97
17	76.26	.7150	105.61	77.07	.7077	101.32	78.49	.6943	94.03
18	55.86	.8714	318.77	56.18	.8698	313.93	61.68	.8406	243.22
19	65.09	.8695	313.03	59.26	.8932	398.43	74.21	.8264	217.54

APPENDIX B-6: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship D (N=56).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.10	.5831	27.82	1.09	.5913	29.03	1.14	.5427	22.54
2	1.54	.5826	27.74	1.53	.5962	29.78	1.60	.5422	22.49
3	2.43	.5815	27.60	2.39	.5960	29.75	2.51	.5405	22.28
4	3.32	.5836	27.90	3.28	.5967	29.86	3.42	.5476	23.13
5	4.34	.5851	28.12	4.29	.5972	29.92	4.46	.5522	23.69
6	5.76	.6022	30.72	5.92	.5724	26.31	5.87	.5824	27.72
7	7.62	.6267	34.94	7.74	.6123	32.39	7.78	.6063	31.39
8	12.77	.6674	43.36	12.62	.6770	45.68	13.12	.6438	38.23
9	23.27	.6348	36.45	22.82	.6524	40.02	27.26	.4251	11.91
10	33.86	.5921	29.15	33.06	.6173	33.23	34.46	.5724	26.31
11	41.96	.5716	26.20	40.75	.6042	31.04	42.53	.5551	24.04
12	68.28	.5361	21.78	66.15	.5755	26.74	69.39	.5140	19.38
13	90.54	.4958	17.60	86.96	.5516	23.63	92.09	.4688	15.21
14	110.46	.5256	20.62	106.37	.5735	26.46	111.25	.5158	19.57
15	117.95	.5779	27.08	115.90	.5974	29.96	117.46	.5827	27.76
16	100.25	.7104	55.03	99.81	.7134	55.99	98.27	.7239	59.47
17	77.81	.8283	118.04	77.57	.8295	119.09	78.49	.8250	115.06
18	63.98	.9166	283.99	68.23	.9046	243.19	69.38	.9012	233.39
19	68.77	.9325	360.22	89.65	.8823	189.73	73.62	.9223	307.43

APPENDIX B-7: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship E (N=62).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.94	.4383	14.26	2.08	.2604	4.36	1.94	.4315	13.73
2	2.72	.4392	14.34	2.91	.2728	4.82	2.73	.4322	13.79
3	4.26	.4393	14.35	4.56	.2755	4.93	4.27	.4321	13.77
4	5.83	.4405	14.44	6.24	.2816	5.17	5.86	.4336	13.89
5	7.63	.4414	14.52	8.15	.2853	5.31	7.66	.4344	13.96
6	10.26	.4371	14.17	11.34	.1072	0.70	10.22	.4433	14.68
7	13.55	.4101	12.13	14.72	.1378	1.16	13.50	.4181	12.71
8	23.13	.3617	9.03	23.75	.2893	5.48	23.16	.3585	8.85
9	38.91	.3471	8.22	42.42	.0	-2.60	51.94	.0	-21.71
10	50.89	.1838	2.10	55.55	.0	-7.88	50.81	.1918	2.29
11	56.13	.0	-1.24	62.01	.0	-11.86	55.92	.0	-0.79
12	81.05	.2404	3.68	86.75	.0	-4.42	80.21	.2778	5.02
13	98.40	.4239	13.14	108.97	.0	-0.37	97.43	.4424	14.60
14	112.66	.5709	29.00	132.01	.2729	4.83	112.35	.5741	29.50
15	118.39	.6717	49.33	141.70	.4623	16.31	117.15	.6801	51.64
16	110.86	.7503	77.27	134.13	.6002	33.77	106.56	.7721	88.57
17	92.26	.8199	123.06	98.65	.7908	100.11	90.80	.8261	129.00
18	88.44	.8843	215.15	99.44	.8511	157.68	83.21	.8983	250.83
19	101.38	.8942	239.47	150.05	.7491	76.71	110.24	.8736	193.28

APPENDIX B-8: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship N (N=69).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.59	.5385	27.36	2.00	.0	-7.26	1.59	.5420	27.88
2	2.24	.5348	26.84	2.83	.0	-7.88	2.23	.5423	27.91
3	3.52	.5343	26.78	4.44	.0	-8.07	3.50	.5421	27.89
4	4.79	.5424	27.93	6.03	.0	-7.23	4.76	.5505	29.14
5	6.25	.5486	28.85	7.87	.0	-6.53	6.20	.5579	30.26
6	10.15	.6094	39.59	11.21	.4829	20.38	10.21	.6032	38.33
7	15.79	.6181	41.41	16.44	.5749	33.07	15.86	.6138	40.51
8	29.94	.5963	36.98	30.63	.5706	32.35	29.84	.5999	37.67
9	50.08	.5534	29.58	52.65	.4829	20.38	61.91	.0	-3.80
10	64.62	.5215	25.03	67.93	.4423	16.29	64.53	.5236	25.31
11	70.54	.5079	23.29	73.85	.4320	15.37	70.59	.5068	23.15
12	94.41	.4378	15.89	101.61	.2524	4.56	93.17	.4612	18.10
13	108.18	.4756	19.59	121.66	.1463	1.47	106.64	.4981	22.11
14	118.46	.4902	21.20	143.16	.0	-6.60	118.90	.4846	20.55
15	135.20	.5799	33.96	167.71	.0	-1.39	134.71	.5840	34.69
16	147.62	.5651	31.43	174.83	.2128	3.18	146.38	.5751	33.11
17	139.22	.4939	21.62	157.58	.1772	2.17	135.97	.5280	25.90
18	129.88	.4792	19.97	141.60	.2903	6.17	129.95	.4783	19.88
19	109.84	.8063	124.53	150.24	.5878	35.37	138.03	.6690	54.29

APPENDIX B-9: Verification statistics resulting from application of COEF-1, COEF-2N, and COEF-2S to OSV-2 soundings from Ship V (N=64).

	COEF-1			COEF-2N			COEF-2S		
LEVEL	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F	STD. ERR.	R_{EFF}	F
1	1.22	.6622	48.41	1.64	.0	-1.00	1.25	.6350	41.89
2	1.71	.6598	47.81	2.31	.0	-1.66	1.76	.6361	42.14
3	2.69	.6594	47.69	3.63	.0	-2.04	2.76	.6358	42.08
4	3.66	.6634	48.73	4.96	.0	-1.82	3.73	.6478	44.83
5	4.78	.6651	49.18	6.49	.0	-1.68	4.84	.6538	46.29
6	6.52	.7133	64.22	7.87	.5323	24.51	6.57	.7080	62.30
7	9.55	.7060	61.63	10.25	.6495	45.24	9.54	.7067	61.84
8	19.11	.7004	59.71	18.31	.7297	70.61	19.15	.6989	59.20
9	35.94	.7194	66.54	34.96	.7372	73.80	57.63	.0	-12.01
10	45.89	.7006	59.79	45.94	.6999	59.52	47.17	.6798	53.26
11	53.08	.6888	55.98	54.85	.6623	48.45	54.34	.6702	50.57
12	74.99	.6450	44.16	84.36	.5108	21.89	75.70	.6363	42.19
13	93.80	.6570	47.11	104.95	.5372	25.15	95.31	.6429	43.67
14	114.25	.6611	48.11	124.47	.5759	30.78	115.64	.6505	45.49
15	126.61	.7111	63.41	140.29	.6269	40.15	124.73	.7212	67.23
16	114.81	.7819	97.50	129.14	.7129	64.08	111.52	.7958	107.07
17	108.88	.8015	111.39	121.63	.7442	76.95	107.60	.8067	115.56
18	105.07	.8478	158.41	125.87	.7722	91.59	97.37	.8709	194.62
19	118.72	.8684	190.14	165.34	.7233	68.00	114.31	.8786	209.96

LIST OF REFERENCES

1. Crow, E.L., Davis, F.A., and Maxfield, M.W., Statistics Manual, p. 168-179, U.S. Naval Ordnance Test Station, China Lake, California, 1955.

2. Dixon, W.J., Biomedical Computer Programs, p. 331-351, Los Angeles Health Sciences Computing Facility, University of California, Los Angeles, 1966.

3. McMillin, L.M., Wark, D.Q., Siomkajlo, J.M., Abel, P.G., Webowetski, A., Lauritson, L.A., Prichard, J.A., Crosby, D.S., Woolf, H.M., Luebbe, R.C., Weinreb, M.P., Fleming, H.E., Bittner, F.E., Hayden, C.M., "Satellite Infrared Soundings from NOAA Spacecraft," NOAA Technical Report 65, p. 56, Washington, D.C., 1973.

4. List, R.J., Smithsonian Meteorological Tables, p. 350, Smithsonian Institute, Washington, D.C., 1963.

5. Smith, W.L., "Note on the Relationship Between Total Precipitable Water and Surface Dew Point," Journal of Applied Meteorology, Vol. 5, pp. 726-727, October 1966.

6. Weinreb, M.P., and Crosby, D.S., 1973, "Estimation of Atmospheric Moisture Profiles from Satellite Measurements by a Combination of Linear and Non-Linear Methods," Preprints Third Conference on Probability and Statistics in Atmospheric Science, Boulder, Colorado, American Meteorological Society, pp. 231-235.

7. "Radiosonde Observations," Federal Meteorological Handbook No. 3, pp. B4-1-48, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C., 1969.

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